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ON THE FORMER CLIMATE OF THE POLAR REGIONS.¹

BY PROFESSOR A. E. NORDENSKIÖLD.

ONLY a few years ago it was looked upon as an article of faith among geologists that the whole globe was once in a melted, incandescent state, and that the conditions of temperature now prevailing on the surface of the earth have been in process of time produced by the slow, gradual cooling of the once fused and glowing mass. It then appeared so natural that, in consequence of the earth's internal heat, a tropical climate should extend from pole to pole, that no special weight was attached to the evidences of this fact which geology was at that time able to produce. The Dane Giesecke's and the English Scoresby's specimens of fossil plants from the east and west coasts of Greenland, evidencing a warm climate there, attracted so little attention that neither they, nor the fossil remains of Saurians found by the famous Arctic traveler, Sir Edward Belcher, in the American Polar Archipelago, could be found in the museums to which they had been confided.

It was not till geologists had become fully convinced that the gradual transition from the time when a warm climate was supposed to have prevailed over the whole earth and the present time has at least once been interrupted by a period during which the greater part of the European and American continents were covered by mighty glaciers, that the geological theory of climates was taken up with real interest. People began gradually to perceive that, even supposing the earth really to have once been in a state of glowing fusion, the cooling must already at the Cambrian and Silurian epochs have proceeded so far that the quantity of heat which the earth lost by radiation was fully compensated by that which it received from the other heavenly bodies. It has also been supposed that the cause of the glacial period — when vast ice mountains scattered boulders from Scandinavia over the plains of Northern Germany, and when the Swiss Alps formed the centre of an icy desert similar to the present Greenland — is to be sought for in some trifling changes in the form of the earth's orbit and the inclination of the equator, which have taken place and continue to take place periodically after the lapse of thousands or hundreds of thousands of years. The same causes which have once produced the glacial period have thus happened, not only during this last period nearer to our own

¹ A lecture delivered at the anniversary meeting of the Royal Swedish Academy of Science, March 31, 1875, and translated for *The Geological Magazine*.

time, but also many times before; and there is reason to suppose that they were also then followed by somewhat similar results, — that is to say, that the cold and the warm eras have many times alternated on the surface of the earth. In consequence of this, it has become a matter of the utmost importance to science to obtain by real observation accurate information as to the state of temperature on the earth's surface during as many of the different geological periods as possible. When in our days a scientific question is seriously propounded, it is seldom long before it is answered; and even in the instance before us we have of late years received numerous contributions to geological climatology from lands the geographical situation of which, in the neighborhood of the pole, renders them best fitted to yield information of this kind.

The geology of the polar tracts can in two different ways supply us with information concerning the former climate, partly by a comparison of the fossil animals and plants there found with existing forms that live under certain determinate climatic conditions, partly by an accurate examination of the various strata of different geological ages, with a view to ascertain whether these present any of the indications which usually distinguish glacial formations.

We now possess fossil remains from the polar regions belonging to almost all the periods into which the geologist has divided the history of the earth. The Silurian fossils which McClintock brought home from the American Polar Archipelago, and the German naturalists from Novaja Semlja, as also some probably Devonian remains of fish found by the Swedish expeditions on the coasts of Spitzbergen, are, however, too few in number, and belong to forms too far removed from those now living, to furnish any sure information relative to the climate in which they have lived.

Immediately after the termination of the Devonian age, an extensive continent seems to have been formed in the polar basin north of Europe, and we still find in Beeren Island and Spitzbergen vast strata of slate, sandstone, and coal, belonging to that period, in which are imbedded abundant remains of a luxuriant vegetation, which, as well as several of the fossil plant-remains brought from the polar regions by the Swedish expeditions, have been examined and described by Professor Heer, of Zürich. We here certainly meet with forms, vast *Sigillaria*, *Calamites*, and species of *Lepidodendron*, etc., which have no exactly correspond-

ing representatives in the plants now existing. Colossal and luxuriant forms of vegetation, however, indicate a climate highly favorable to vegetable development. A careful examination of the petrifications taken from these strata shows also so accurate an agreement with the fossil plants of the same period found in many parts of the continent of Central Europe, that we are obliged to conclude that at that time no appreciable difference of climate existed on the face of the earth, but that a uniform climate extremely favorable for vegetation — but not on that account necessarily tropical — prevailed from the equator to the poles.

The sand and slate beds here mentioned do not contain any marine petrifications, whence we may conclude that they have been formed in lakes or other hollows in an extensive polar continent. In Beeren Island and Spitzbergen they are, however, covered by beds of limestone and siliceous rock, which form the chief material in Beeren Island, and of several considerable mountains on the southern side of Hinloopen Strait, and the innermost bays of Ice-fjord in Spitzbergen. The manner in which these mountains rise several thousand feet above the surrounding snow desert, their regular form, crowned with vast masses of dark volcanic rock divided into vertical columns, the siliceous strata forming perpendicularly scarped terraces, and the tendency of the calcareous beds to fall away and form natural arches, give to these mountains the appearance of ruins of colossal ancient fortifications and temples, unequaled in sublime and desolate magnificence. Here, indeed, we meet with the monumental gravestones of a long-past age. The rock is in fact formed almost entirely of shells of marine mollusca, fragments of corals, and bryozoa of the age of the mountain-limestone. We have then, here, not only a proof that the ancient polar continent sank down again and gave place to a deep polar ocean, but also, in the correspondence of the corals, shells, and other associated organic remains with those met with in more southerly tracts, an indication that the warm polar climate remained unchanged.

The mountain-limestone period was followed by an era during which the richest coal-beds of England, Belgium, and America were formed, and which has accordingly received the name of the coal period. A new distribution of land and water had now taken place, continents had again arisen in the polar tracts, in the sandstones and argillaceous strata of which we again find, at Bell Sound, on the western coast of Spitzbergen, fossil plants

that bear witness to a rich polar vegetation developed under a warm climate. Among these, however, we miss the species of large-leaved fern so abundant in the coal-beds of more southerly lands, a circumstance which may possibly indicate a certain difference of climate as existing at that epoch, unless, as is more probable, the circumstance is merely the result of the insufficiency of the materials brought from but one single arctic locality.

The only relics from the polar regions belonging to the succeeding era, the Triassic, are those of marine animals, amongst which a considerable portion consists of large, shell-clad Cephalopoda related to Ammonites, Nautilus, etc., which, judging from the habits of the forms still existing in our time, could assuredly have only lived in a warm ocean. More certain information relative to the nature of the polar climate at that time is afforded by portions of skeletons of colossal Sauria, — one form, *Ichthyosaurus polaris*, seems to have reached a length of twenty or thirty feet, — which, together with vast coprolite beds, are found in great abundance inclosed in the Triassic strata of Ice-fjord, and which among the now existing fauna have their nearest representatives in the crocodiles on the sunny banks of the Nile, or perhaps rather in the marine lizard, *Amblyrhynchus*, met with in the Galapagos Isles. That multitudes of these cold-blooded animals lived at that time in the vicinity of the eightieth degree of latitude attests beyond all doubt climatal conditions very different from those of the present day.

At the entrance of Ice-fjord and at Mount Agardh, in Stor-fjord, the Triassic strata are covered with marine formations belonging to the immediately subsequent geological era, the Jura period, and, as far as we can judge from the few fossil remains hitherto discovered in these strata, no diminution had as yet taken place in the warmth of the polar climate. But great changes now came to pass in the portion of the polar basin north of Europe, the ocean being again transformed into a continent, which, though shattered and reduced, still exists up to the present time. The upper portion, therefore, of the Jura formation of Spitzbergen does not contain any marine organisms, but in the place of them beds of sandstone and slate, with coal-seams and impressions of plants. From the strata belonging to that age met with at Cape Boheman, in Ice-fjord, situated between the seventy-eighth and seventy-ninth degrees of latitude, the Swedish expeditions have brought home numerous impressions of

palm-like cycadeæ and coniferæ, the representative species of which now flourish in the neighborhood of the tropics. This already leads to the supposition of a warm climate, which supposition is further confirmed by a comparison with the European fossil flora of the same date, which indicates that the climate of Spitzbergen did not then materially differ from that of Central Europe.

The Swedish expeditions have also succeeded in obtaining, partly from Greenland and partly from Spitzbergen, from two separate epochs of the Cretaceous era, extensive collections of fossil plants, lately described by Professor Heer in the Transactions of the Royal Swedish Academy. By this we have been enabled not only to determine the epoch when differences of climate first began to show themselves on the surface of the earth, but also pretty closely to follow an extremely remarkable change in the appearance of the vegetable world which took place during the course of that period.

Within the polar basin we meet with the lowest division of the Cretaceous age on the north side of the Noursoak peninsula, in Northwestern Greenland. The crown of the hills is here composed of black, ancient lava-streams and immense beds of volcanic tuff, hardened in process of time into solid rock.

Over these volcanic formations now rests a covering of perpetual ice, and beneath them on the sea-shore vast strata of sand are discovered, containing inconsiderable coal-beds, interstratified with clay-beds and a fine-grained argillaceous shale singularly fitted for preserving the impressions of fossils that have been imbedded in it. These plants belong to the lowest portion of the Cretaceous age, and among the collections brought from this spot, Heer has succeeded in distinguishing seventy-five different species, among which are thirty ferns, nine cycadeæ, and seventeen coniferæ.

The third part of the ferns belongs to one genus, *Gleichenia*, which still flourishes in the neighborhood of the tropics and warmer parts of the temperate zone, and the same remark holds good of the cycadeæ, most of which are referable to the genus *Zamia*, species of which we meet with within the tropics, as also of the coniferæ, some of which are nearly related to forms still existing in Florida, Japan, and California. From this Heer draws the conclusion, that in the early part of the Cretaceous period the climate of the now ice-covered Greenland was somewhat like that which now prevails in Egypt and the Canary Isles.

Among the ferns, cycadeæ, and coniferæ of Noursoak peninsula, were found a few impressions of a species of the poplar, *Populus primæva*, which formed the only and at the same time the oldest known representative of the forest vegetation now prevailing in the temperate zone. Nevertheless the vegetation of the arctic tracts was already during the Cretaceous period undergoing a complete transformation. Evidence of this has been obtained from the same locality, Atanekrdluk, on the south side of the Noursoak peninsula, from which such magnificent remains of arctic vegetation of the Tertiary period had previously been obtained, from strata at a somewhat higher level. Here, out of the talus that has fallen from the lofty fells, some black and tolerably easily crumbling strata of shale protrude, among which, on careful inspection, impressions of plants may be discovered belonging to the Cretaceous formation, not to the lower, but the upper portion of it. The vegetation is here quite different. The ferns and cycadeæ have disappeared, and in their place we find deciduous trees and other dicotyledons in astonishing variety and forms, among which a species of fig may be mentioned, of which not only the leaves, but also the fruit, have been obtained in a fossil state; two species of magnolia, etc. The climate that then prevailed over the whole globe was therefore still warm and luxuriant, even if, at least in the arctic regions, considerably modified from what it formerly had been, inasmuch as that the flowerless vegetation (which was now beginning to die out), as far as we can judge from its present representatives, the ferns, required a warm, humid climate, whereas the new forms with their luxuriant flowers, which now began to characterize the vegetable world, required, in order to develop all the grandeur of their colors, a clear and sunny sky. The disappearance of sundry tropical and sub-tropical forms that are met with in the older Cretaceous strata has led Heer to the conclusion that difference of climate at different latitudes was now beginning to show itself, and he calls attention to the circumstance that this takes place synchronously with the development of the dicotyledonous plants in greater variety.

Unhappily, in the arctic regions no fossil remains belonging to the Eocene age, which immediately succeeded the Cretaceous period, have hitherto been met with, and we are therefore destitute of the actual data necessary for ascertaining its climatic character. But the next following, or Miocene, age places at our disposal abundant materials in the magnificent remains of

plants obtained, we may say, from all parts of the polar basin and its vicinity: from West Greenland by Inglefield, McClintock, Rink, Torell, Whymper, and the Swedish expeditions; from East Greenland by Payer; from Alaska by Mr. Furnhjelm; from Sagalin by Admiral Furnhjelm; and from different localities of Spitzbergen by the Swedish expeditions.¹ The spots where remains of this period are found are frequently distinguished by their astonishing abundance of fossil plant-remains.

For example, at a place in Spitzbergen which we have called Cape Lyell, after the lately-deceased great English geologist, the rocks on the shore for a distance of several hundred feet form a continuous herbarium, where every stroke of the hammer brings to light an image of the vegetation of a long-past age, when the forest vegetation of these tracts consisted of the swamp-cypress of Texas (*Taxodium distichum*), of gigantic sequoias, relations or ancestors of California's mammoth tree, of large-leaved birches, limes, oaks, beeches, planes, and even magnolias. The place is situated in about 77° 35' N. lat., on the south side of the entrance to Bell Sound, on the western coast of Spitzbergen. At the foot of the cliff, on one or two barren heaps of gravel, one may discover shoots an inch long of the polar willow, sole representative of the present vegetation of the locality. Just off the shore the ocean currents drive icebergs, which have fallen from the neighboring glaciers, backwards and forwards, and the crown of the rock itself forms the limit of a mighty glacier, which threatens within a few years to bury, under an icy covering of several hundred feet thickness, not only the little vegetation that exists here, and which in the summer weeks is sometimes adorned with charming colors, but also the memorials of the ancient glorious age now preserved within its rocks.

By a careful examination of the rich materials here accessible, and by a comparison of the petrifications with those of the same period found in more southerly localities, Heer has shown that already in the Miocene era considerable variety of climate existed on the face of the earth, though even the pole at that time enjoyed a climate fully comparable with that of Central Europe now. The then flora of Europe had almost entirely an American character, and there are many reasons for supposing that the continents of Europe and America were at that time united, and

¹ We may also mention the evidence of an arctic Miocene flora obtained by Sir John Richardson from fine indurated clay-beds, associated with coal-seams, on the Mackenzie River, near Great Bear Lake, from which seventeen species of fossil plants have been identified by Heer. — EDIT. GEOL. MAG.

bounded on the south by an ocean extending from the Atlantic over the present deserts of Sahara and Central Asia to the Pacific.

Between the Miocene and the present era are two important periods, the Pliocene and the Glacial, which to us are particularly deserving of attention, inasmuch as that during them man, the lord of creation, seems first to have made his appearance. That during the latter of these periods vast masses of ice covered at least all the northern part of Europe is a well-known fact; but concerning the nature of the transition from the glorious climate of the Miocene age to the Glacial period we possess no knowledge whatever founded on actual observation. Probably at some future time contributions towards the solution of this important question may be found amongst the mountain masses that occupy the peninsula between Ice-fjord and Bell Sound in Spitzbergen, or in some parts of the basalt region of Northwestern Greenland. In the interior of Ice-fjord and at several other places on the coast of Spitzbergen, one meets with indications either that the polar tracts were less completely covered with ice during the Glacial era than is usually supposed, or that, in conformity with what has been observed in Switzerland, inter-glacial periods have also occurred in the polar regions. In some sand-beds not very much raised above the level of the sea, one may in fact find the large shells of a mussel (*Mytilus edulis*) still living in the waters encircling the Scandinavian coast. It is now no longer found in the sea around Spitzbergen, having been probably rooted out by the ice-masses constantly driven by the ocean currents along the coasts.

From what has been already stated, it appears that the animal and vegetable relics found in the polar regions imbedded in strata deposited in widely separated geological eras uniformly testify that a warm climate has in former times prevailed over the whole globe. *From palæontological science no support can be obtained for the assumption of a periodical alternation of warm and cold climates on the surface of the earth.*

A careful investigation of the structure of the different sedimentary strata leads to the same result. We are now very well acquainted with the origin and nature of the various strata, the substance of which has been supplied by the destructive operation of glaciers on the surrounding and subjacent mountain masses, and we can point out certain marks by which these strata may be distinguished from other non-glacial deposits. In

these last, one very rarely meets with any large stone bowlders, which have fallen from some neighboring cliff and been imbedded in sand or clay, either directly, and, if so, close to the place where originally found, or else after having in the spring been moved a greater or less distance by river ice. In glacial formations, on the contrary, as one may gather from the study of the strata in Scandinavia that belong to the glacial period, erratic blocks transported on icebergs to far-distant regions play an important part. If a climate similar to that which now prevails in the arctic regions has several times during various geological eras existed in the neighborhood of the pole, one has reason to expect that sandstones inclosing large bowlders should often be met with in these tracts.

But this is by no means the case, though such formations, if they exist on a large scale, could hardly escape observation.

The character of the coasts in the arctic regions is especially favorable to geological investigations. While the valleys are for the most part filled with ice, the sides of the mountains in summer, even in the eightieth degree of latitude, and to a height of one thousand or fifteen hundred feet above the level of the sea, are almost wholly free from snow. Nor are the rocks covered with any amount of vegetation worth mentioning, and, moreover, the sides of the mountains on the shore itself frequently present perpendicular sections, which everywhere expose their bare surfaces to the investigator. The knowledge of a mountain's geognostic character, at which one in more southerly countries can only arrive after long and laborious researches, removal of soil, and the like, is here gained almost at the first glance; and as we have never seen in Spitzbergen nor in Greenland, in these sections, often many miles in length, and including, one may say, all formations from the Silurian to the Tertiary, any bowlders even as large as a child's head, there is not the smallest probability that strata of any considerable extent, containing bowlders, are to be found in the polar tracts previously to the middle of the Tertiary period.

Since, then, both an examination of the geognostic condition and an investigation of the fossil flora and fauna of the polar lands show no signs of a Glacial era having existed in those parts before the termination of the Miocene period, we are fully justified in rejecting, on the evidence of actual observation, the hypotheses founded on purely theoretical speculations, which assume the many times repeated alternation of warm and glacial climates between the present time and the earliest geological ages.